ASSESSMENT REPORT ON

2-ETHYLHEXANOL

FOR DEVELOPING AMBIENT AIR QUALITY OBJECTIVES

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ASSESSMENT REPORT ON 2-ETHYLHEXANOL FOR DEVELOPING AMBIENT AIR QUALITY OBJECTIVES

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FOREWORD

Alberta Environment maintains Ambient Air Quality Objectives[1] to support air quality management in Alberta. Alberta Environment currently has ambient objectives for more than thirty substances and five related parameters. These objectives are periodically updated and new objectives are developed as required.

With the assistance of the Clean Air Strategic Alliance, a multi-stakeholder workshop was held in October 2000 to set Alberta's priorities for the next three years. Based on those recommendations and the internally identified priority items by Alberta Environment, a three-year work plan ending March 31, 2004 was developed to review four existing objectives, create three new objectives for three families of substances, and adopt six new objectives from other jurisdictions.

In order to develop a new three-year work plan, a multi-stakeholder workshop was held in October 2004. This study was commissioned in preparation for the workshop to provide background information on alternative, science based, and cost effective methods for setting priorities.

This document is one of a series of documents that presents the scientific assessment for these adopted substances.

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[1] **NOTE**: The *Environmental Protection and Enhancement Act*, Part 1, Section 14(1) refers to "ambient environmental quality objectives" and uses the term "guidelines" in Section 14(4) to refer to "procedures, practices and methods for monitoring, analysis and predictive assessment." For consistency with the *Act*, the historical term "ambient air quality guidelines" is being replaced by the term "ambient air quality objectives." This document was prepared as the change in usage was taking place. Consequently any occurrences of "air quality guideline" in an Alberta context should be read as "air quality objective."

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ACRONYMS AND ABBREVIATIONS

AAQC	Ambient Air Quality Criterion
ACGIH	American Conference of Governmental Industrial Hygienists
AENV	Alberta Environment
ATSDR	Agency for Toxic Substances and Disease Registry
CNS	Central Nervous System
EC_{50}	Effects Concentration resulting in 50% response
GC/FID/MS	Gas Chromatography/Flame Ionization or Mass Spectrometry Detection
HSDB	Hazardous Substances Database
IPCS	International Programme on Chemical Safety
LOAEL	Lowest Observable Adverse Effect Level
MRL	Minimum Risk Level
MOE	Ministry of the Environment
MW	Molecular Weight
NIST	National Institute of Standards and Technology
NIOSH	National Institute for Occupational Safety and Health
NOAEL	No Observable Adverse Effect Level
NPRI	National Pollutant Release Inventory
OECD	Organization for Economic Cooperation and Development
OEL	Occupational Exposure Limit
OSHA	Occupational Safety and Health Administration
POI	Point of Impingement
PVC	Polyvinyl chloride
STEL	Short-Term Exposure Limit
TDI	Tolerable Daily Intake
TLV	Threshold Limit Value
TWA	Time Weighted Average
US EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WHO	World Health Organization

SUMMARY

2-Ethylhexanol is a clear, colourless liquid with an odour described as sweet, floral, intense, and unpleasant. It occurs naturally in food and is also added as flavouring to foods. This compound is formulated by petrochemical synthesis and used predominately in the production of plasticizers for PVC resins, hexyl esters, and arylates. 2-Ethylhexanol is also used in textiles and as a solvent and wetting agent.

In the atmosphere, 2-ethylhexanol occurs in the vapour phase and will undergo atmospheric degradation via photochemically produced hydroxyl radicals. It is only moderately soluble in water, from which it will volatilize or undergo biodegradation. This compound is unlikely to adsorb to sediments or soil.

Plants, including a variety of fruits, are a natural source of 2-ethylhexanol emissions. Anthropogenic emission sources of 2-ethylhexanol include those resulting from its manufacturing and use as a solvent. It is also released in the manufacturing of plasticizers, plastics, coatings, cetane improvers, lubricant additives, and surfactants. 2-Ethylhexanol is formed from combustion of PVC plastics and disinfection of water and wastewater using chlorine dioxide. In indoor environments, 2-ethylhexanol is emitted from some carpeting. 2-Ethylhexanol is currently not a reportable substance for Environment Canada's National Pollutant Release Inventory.

In humans and animals, toxicity endpoints associated with acute 2-ethylhexanol inhalation include irritation of eyes and throat, headaches, cough, dizziness, and fatigue. There is limited evidence to suggest acute, reversible neurotoxicity. No chronic effects were reported in either animal or human studies. Animal studies have concluded that 2-ethylhexanol is neither genotoxic nor carcinogenic. No data was identified for the effects of 2-ethylhexanol on terrestrial vegetation. In algae (*Chlorella emersonii*), 50 and 100 mg dm^3 2-ethylhexanol added to growth medium severely inhibited algal growth rate.

The standard method for monitoring 2-ethylhexanol in air employs the use of charcoal solid sorbent tubes. Reference air monitoring methods were limited to one method developed, tested and reported by the Occupational Safety and Health Administration (OSHA).

Ambient air quality guidelines or objectives were developed for 2-ethylhexanol by only 5 of the 22 agencies evaluated. These agencies included: Ontario, Texas, Oklahoma, Michigan, and Vermont. Where reported, the basis for the guideline or objective was odour. No guidelines were developed based on occupational exposure criteria as there were no occupational criteria for 2-ethylhexanol.

1.0 INTRODUCTION

Ambient air quality objectives are established by Alberta Environment as part of the Alberta air quality management system, Section 14 of the Environmental Protection and Enhancement Act (AENV, 2000). The purpose of this assessment report was to provide a review of scientific and technical information to assist in evaluating the basis and background for an ambient air quality objective for 2-ethylhexanol. The following aspects were examined as part of the review:

- Physical and chemical properties;
- Existing and potential anthropogenic emissions sources in Alberta;
- Effects on humans, animals, and vegetation;
- Monitoring techniques, and;
- Ambient air guidelines and objectives in other Canadian jurisdictions, United States, World Health Organization and New Zealand, and the basis for development and use.

The physical and chemical properties identified for 2-ethylhexanol include chemical structure, molecular weight, melting and boiling points, water solubility, density, vapor density, organic carbon partition coefficient, octanol water partition coefficient, vapor pressure, Henry's Law constant, bioconcentration factor, and odour threshold. A discussion of the behaviour of 2-ethylhexanol in the environment was also presented.

Existing and potential natural and anthropogenic sources of 2-ethylhexanol emissions in Alberta were examined. The chemical is currently not a reportable substance on Environment Canada's National Pollutant Release Inventory.

Scientific information about the effects of 2-ethylhexanol on humans, animals, and vegetation were identified. Limited data on effects in animals and humans was available from toxicity and epidemiology studies cited in peer reviewed evaluations by the World Health Organization and listed on Toxline and Medline databases. Information on the effects of 2-ethylhexanol on vegetation were limited to one study.

Air sampling and analytical methods for 2-ethylhexanol used in practice by regulatory agencies were included in this assessment. Reference air monitoring methods were limited to one method developed, tested and reported by the Occupational Safety and Health Administration (OSHA).

Few ambient air quality guidelines were identified for 2-ethylhexanol following a review of jurisdictions in North America, Europe and elsewhere. Though typically developed using an occupational exposure level, no such exposure criteria has been established for 2-ethylhexanol. The bases for the guidelines in use by different jurisdiction were investigated in this report.

2.0 GENERAL SUBSTANCE INFORMATION

2-Ethylhexanol is a clear, colourless liquid with a characteristic odour (IPCS, 2001), which has been described as sweet and floral (Genium, 1999; WHO, 1993) and as intense and unpleasant

(HSDB, 2004; Verschueren, 2001). This compound occurs naturally in food (*e.g.*, corn, olive oil, tobacco, tea, rice, apricots, plums, apples, nectarines, tamarind grapes, and blueberries) and is also used as a flavor additive in foods (HSDB, 2004; WHO, 1993). In the atmosphere, 2-ethylhexanol occurs as a vapour (Genium, 1999). This compound is combustible and will react violently with oxidizing materials and strong acids (IPCS, 2000; Lewis, 1997). 2-Ethylhexanol is soluble in organic solvents (HSDB, 2004) but only moderately soluble in water (Genium, 1999).

The chemical formula, structure, registry numbers, synonyms and trade names for 2-ethyl hexanol are provided in Table 1 (NIST, 2003).

Table 1 Identification of 2-Ethylhexanol

Property	Value
Formula	$C_8H_{18}O$
Structure	
CAS Registry number	104-76-7
RTECS number[1]	MP0350000
Synonyms	2-Ethylhexanol; 2-Ethyl-1-hexanol; Ethylhexanol; 2-Ethylhexyl alcohol; 2-Ethyl-hexanol-1; Ethylhexyl alcohol; 2-EH; Aerofroth 88; Octyl alcohol; Surfynol 104A

[1] Genium, 1999

2-Ethylhexanol is formulated by petrochemical synthesis (WHO, 1993). In 1992, the prevailing worldwide use of 2-ethylhexanol was in the production of plasticizers for PVC resins, hexyl esters and arylates (OECD, 1995). 2-Ethylhexanol is also used as a solvent (dyes, resins, oils, antifoaming agents and nitrocellulose), a wetting agent (organic synthesis, paint lacquer, baking finishes, inks, rubber, paper, lubricant, photography and dry cleaning) and in textiles (finishing compounds and mercerizing textiles) (Verschueren, 2001; Genium, 1999). In addition, the WHO reported an annual production of 209 kilograms of 2-ethylhexanol for use as a flavour additive to food (WHO, 1993).

2.1 Physical, Chemical and Biological Properties

The physical and chemical properties of 2-ethylhexanol are summarized in Table 2.

Table 2 Physical and Chemical Properties of 2-Ethylhexanol

Property	Value	Reference
Molecular Weight	130.23 g/mol	Verschueren, 2001
Physical State	Liquid	Verschueren, 2001
Melting Point	-76 °C	Verschueren, 2001
Boiling Point	183.5 °C	Verschueren, 2001
Specific gravity (liquid)	0.8344 at 20 °C	Genium, 1999
Specific gravity (gas) (air=1)	4.49	Genium, 1999
Vapour Pressure	0.05 mmHg at 20 °C 0.20 mmHg at 20 °C	Verschueren, 2001 Lewis, 1997
Solubility	Soluble in organic solvents	Genium, 1999
Solubility in water	880 mg/l at 25 °C 1000 mg/l at 20 °C	HSDB, 2004 Verschueren, 2001
Henrys Law Constant	2.65×10^{-5} atm-m^3/mol	Genium, 1999
Octanol water partition coefficient (log K_{ow})	2.81	Chemfate, 2003
Organic carbon partition coefficient (K_{oc})	105	Genium, 1999
Flash Point	81 °C	Genium, 1999
Explosive limits	0.88% to 9.7%	Genium, 1999
Autoignition temperature	231 °C	Genium, 1999
Odour threshold	0.075 ppm (perception) 0.138 ppm (100% recognition)	Verschueren, 2001
Bioconcentration factor in fish (Log BCF)	1.13	Chemfate, 2003
Conversion factors for vapour (at 20 °C and 101.3 kPa)	1 ppm = 5.41 mg/m^3	Verschueren, 2001

2.2 Environmental Fate

During commercial operations, 2-ethylhexanol is typically released to the environment as an air emission or in wastewater (HSDB, 2004). In the atmosphere, vapour phase 2-ethylhexanol is degraded by photochemically produced hydroxyl radicals (Genium, 1999). In water, 2-ethylhexanol will volatilize to air or undergo biodegradation, it is not expected to adsorb to

sediments or bioconcentrate in aquatic receptors (Genium, 1999). If released to soil 2-ethylhexanol will likely volatilize from the surface or migrate to water, adsorption to soil is not significant (HSDB, 2004; Genium, 1999).

A summary of the environmental fate and half-lives for 2-ethylhexanol is provided in Table 3 (HSDB, 2004).

Table 3 Environmental Fate of 2-Ethylhexanol

System	Fate	Half life
Water	Biodegradation and volaltilization from surface.	Estimated half-life in surface water (model river) due to volatilization: 1.7 days.
Soil	Biodegradation, volatilization and leaching to groundwater.	
Air	Degradation via reaction with hydroxyl radicals.	Atmospheric half-life of 1.2 days due to reaction with hydroxyl radicals.

3.0 EMISSION SOURCES AND INVENTORIES

3.1 Emission Sources and Ambient Levels

2-Ethylhexanol is emitted to the atmosphere via both natural and anthropogenic sources. These emissions sources, as well as ambient levels, are described in more detail in the following sections.

3.1.1 Natural Sources

2-Ethylhexanol is emitted to the air from plants. It has been identified as a volatile compound emitted from a variety of fruits including cassava, apricots, plums, apples, and nectarines (Dougan *et al.* cited in HSDB, 2004; Gomez *et al.* cited in HSDB, 2004; Mattheirs *et al.* cited in HSDB, 2004; Takeoka *et al.* cited in HSDB, 2004.)

3.1.2 Anthropogenic Sources

Anthropogenic sources of 2-ethylhexanol to the atmosphere are largely the result of emissions during its manufacturing, transport, storage, disposal and use as a solvent (Staples, 2001) or in the manufacturing of plasticizers, plastics, coatings, cetane improvers, lubricant additives and surfactants (Staples, Bahrmann and Hahn, 2002; RSC, 1999; Kavaler cited in HSDB, 2004). 2-Ethylhexanol can also be formed during the combustion of PVC plastics and as a byproduct during the disinfection of water and wastewater using chlorine dioxide: these sources may contribute to 2-ethylhexanol emissions to air (HSDB, 2004). 2-Ethylhexanol has also been reported in indoor air as the result of emissions from some carpeting (Wolkoff cited in HSDB, 2004; Hodgson *et al.* cited in HSDB, 2004; Pleil and Whiton cited in HSDB, 2004).

2-Ethylhexanol is also considered "a meat flavouring volatile" (HSDB, 2004) and it has been found in raw beef (King *et al.* cited in HSDB, 2004), duck meat (Wu and Liou cited in HSDB, 2004), and fried bacon (Ho *et al.* cited in HSDB, 2004).

2-Ethylhexanol is currently not a reportable substance for Environment Canada's National Pollutant Release Inventory (NPRI) and therefore no emission data is provided.

3.1.3 Ambient Levels

Only ambient levels of 2-ethylhexanol in indoor air were provided by HSDB (2004). HSDB (2004) reports that a study performed in Germany identified 2-ethylhexanol in indoor air at concentrations ranging from less than 1 $\mu g/m^3$ to 10 $\mu g/m^3$ (Otson and Fellin cited in HSDB, 2004).

4.0 EFFECTS ON HUMANS, ANIMALS AND VEGETATION

The following is a summary of the available toxicological and epidemiological studies on the health effects of 2-ethylhexanol following inhalation. Studies were identified in peer reviewed safety evaluations prepared by the Joint FAO/WHO Expert Committee on Food Additives (WHO, 1993; 1998) and following an on-line literature search of Toxline and Medline databases for studies published between 1990 and November 2003.

The focus of this assessment was adverse health effects associated with inhalation exposure to 2-ethylhexanol. Due to a lack of human or animal chronic inhalation studies, the available studies on the carcinogenic potential of 2-ethylhexanol following chronic oral (gavage) exposure of animals were included. Exposure-response data from key toxicological studies were summarized in table form to provide a quick reference to health effects observed in critical receptors over a defined period of inhalation exposure to 2-ethylhexanol. The relevance of this data to public health was then discussed.

4.1 Overview of Chemical Disposition

4.1.1 Absorption, Distribution, Metabolism and Excretion

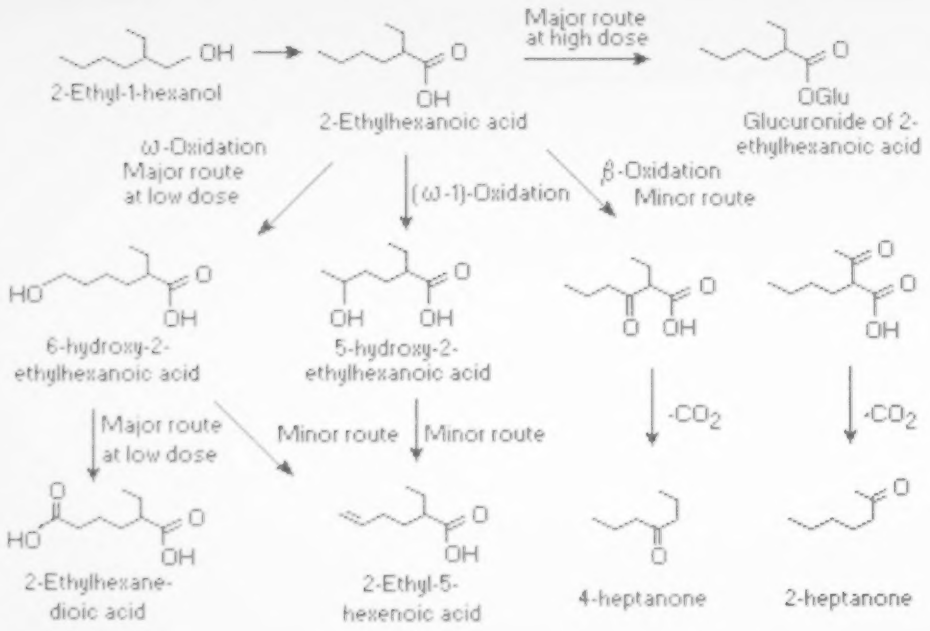
The absorption, distribution, excretion, and metabolism of 2-ethylhexanol have been studied in animals primarily via oral exposure. No data was available for human exposure to 2-ethylhexanol.

Ingestion of 2-ethylhexanol by rats and rabbits resulted in rapid and extensive (>95%) absorption (OECD, 1995). By comparison, 2-ethylhexanol was poorly absorbed (≤5%) by rats and rabbits following dermal exposure (Deisinger *et al.* cited in WHO, 1993; OECD, 1995). Studies in Fischer rats, B6C3F1 mice and cynomolgus monkeys indicated that 2-ethylhexanol was well absorbed through the gastrointestinal tract, although 2-ethylhexanol metabolism in the monkey was less extensive than the rodent species (Midwest Research Institute cited in WHO, 1993). Oral administration of 2-ethylhexanol to rats resulted in distribution to the heart, brain, liver, and kidney (Albro, cited in WHO, 1993). Target organs identified in studies on oral and inhalation exposures of rats and rabbits include liver, kidney and stomach (OECD, 1995).

Female Fischer rats were orally exposed to "high" (500 mg/kg body weight/day) and "low" (50 mg/kg body weight/day) 2-ethylhexanol doses to determine the metabolic pathways for urinary elimination (Albro, Deisinger *et al.* in WHO, 1993). At the low dose, the major urinary elimination pathway was omega oxidation with minor amounts of beta oxidation. At the high dose, urinary elimination primarily occurred via conjugation with glucuronic acid. The metabolites formed by each pathway are illustrated in Figure 1.

The elimination of 2-ethylhexanol occurred within 24-28 hours of exposure via urine (80-82%), faeces (8-9%), and exhaled CO_2 (6-7%). Approximately 3% was excreted unchanged in urine (Albro, Deisinger *et al.* cited in WHO, 1993).

Figure 1. Metabolism of 2-ethyl-1-hexanol



(WHO, 1993)

4.1.2 Effects on Enzyme Systems

Several *in vivo* studies of enzyme systems have demonstrated that oral and gavage exposure to 2-ethylhexanol over a period of 14 to 21 days stimulated liver peroxisome proliferation in rats and mice at doses ≥ 320 mg/kg body weight/day (Rhodes *et al*, Moody & Reddy, Hodgson, and Keith, cited in WHO, 1993). The activity of rat liver enzymes (peroxidase, catalase, carnitine acetyltransferase, lauric acid hydroxylase, alcohol dehydrogenase, and biphenyl 4-hydroxylase) increased as a result of 2-week *in vivo* exposure to oral 2-ethylhexanol doses ≥950 mg/kg body weight/day (Moody & Reddy, Hodgson, Lake *et al.* cited in WHO, 1993; Lake *et al.* cited in WHO, 1998). An increase in succinate dehydrogenase activity was reported for rats following 12 days of dermal application of 2-ethylhexanol at 2 ml/kg body weight/day (Schmidt *et al.* cited in WHO, 1993). Decreased activities of glucose-6-phosphatase and lactic dehydrogenase were reported following oral and dermal exposure to 2-ethylhexanol, respectively (Lake *et al*, Schmidt *et al.* cited in WHO, 1993).

The above *in vivo* studies also reported significantly increased liver weights in rodents exposed by gavage and in the diet to high concentrations of 2-ethylhexanol (Keith *et al.* cited in WHO, 1993; Lake *et al.* and Astill *et al.* cited in WHO, 1998). The increased liver weights occurred in rats exposed by gavage to 2-ethylhexanol at 1335 mg/kg body weight /day for 7 days (Lake *et al.* cited in WHO, 1998) in mice and rats exposed by gavage for 14 days to ≥700 mg/kg body weight/day (Keith *et al.* cited in WHO, 1993) and in rats exposed in the diet to 500 mg/kg body weight per day for 11 days (Astill *et al.* cited in WHO, 1998).

In vitro studies of enzymes in rat liver cells suggest that 2-ethylhexanol-induced liver peroxisome proliferation occurs as a result of high exposure doses. No evidence of proliferation was observed in cultures of rat hepatocytes exposed to 0.1, 0.2, or 0.5 mmol 2-ethylhexanol (Rhodes *et al*, Gray *et al.* cited in WHO, 1993), however, significant induction of carnitine acetyltransferase (a peroxisomal enzyme) occurred in rat liver cells treated with 1 mmol 2-ethylhexanol (Gray *et al.* cited in WHO, 1993). The inhibition of rat liver enzymes (aminopyrine N-demethylase and aniline hydroxylase) was significant following incubation with 2-ethylhexanol doses ranging from 2.5 to 15 mmol 2-ethylhexanol (Seth, cited in WHO, 1993). The incubation of rat liver plugs with lower 2-ethylhexanol concentrations (0.1 to 3 mmol) decreased urea synthesis and caused cell damage (Liang *et al.* cited in WHO, 1993).

In vitro studies by Keller and colleagues (Keller *et al.* 1990; Badr *et al.* 1990; Keller *et al.* 1991; 1992) evaluated the mode of action of 2-ethylhexanol on rat liver mitochondria. These studies reported the ability of lipophilic 2-ethylhexanol (3 mmol) to uncouple oxidative phosphorylation in actively respiring mitochondria and result in localized toxicity (Keller *et al.* 1991; 1992). A dose-dependent decrease in the rate of ketone body production by mitochondria also occurred following *in vitro* exposure of rat liver to 0.2 mmol 2-ethylhexanol (Keller *et al.* 1990; Badr *et al.* 1990). The authors concluded that 2-ethylhexanol exposure alters hepatic fatty acid metabolism in liver mitochondria which may be a precursor event to peroxisome proliferation and liver toxicity (Badr *et al.* 1990).

4.2 Genotoxicity

Numerous *in vitro* and *in vivo* assays for genotoxicity have been conducted using 2-ethylhexanol in various test systems (WHO, 1993; 1998). With one exception, all of the assays reported for 2-ethylhexanol was negative for genotoxicity.

A single positive result was reported for an *in vitro* 8-Azaguanine resistance assay conducted in *Salmonella Typhimurium* TA100 without metabolic activation (Seed cited in WHO, 1993 and WHO, 1998). However, it should be noted that this positive result occurred in the presence of significant cytotoxicity (WHO, 1993).

Negative results were obtained from numerous *in vitro* Ames tests in *Salmonella Typhimurium* (TA98, TA100, TA1535, TA1537, TA1538, and TA2637) conducted with and without metabolic activation (Kirby *et al.* Zeiger *et al.* Agarwal *et al.* Litton Bionetics Inc., DiVencenzo *et al.* cited in WHO, 1993 and WHO 1998). *In vitro* studies on DNA damage were also negative for cell transformation in BALB/3T3 cells (Litton Bionetics Inc, cited in WHO, 1993), gene mutation in Chinese hamster ovary cells (Phillips *et al.* cited in WHO, 1993 and WHO, 1998), unscheduled DNA synthesis in primary rat hepatocytes (Hodgson *et al.* cited in WHO, 1998), rec-assay in *Bacillus subtilis* (Tomita *et al.* cited in WHO, 1993 and WHO, 1998), and mouse lymphoma assay in L5178Y/TK$^{+/-}$ mouse lymphoma cells (Kirby *et al*cited in WHO, 1993 and WHO, 1998).

The results of genotoxicity studies of mice and rats exposed *in vivo* to 2-ethylhexanol were also negative (WHO, 1993; WHO, 1998). These studies included an *in vivo* dominant lethal assay in ICR/SIM mice (Rushbrook *et al.* cited in WHO, 1993 and WHO, 1998), an *in vivo* chromosomal aberration assay of F344 rat bone marrow cells (Putnam *et al.* cited in WHO, 1993 and WHO,

1998), and a mouse micronucleus test in B6C3F1 mouse bone marrow cells (Litton Bionetics Inc., cited in WHO, 1993).

4.3 Acute and Sub-Acute Effects

Acute effects occur rapidly as a result of short-term exposures (less than 24 hours), while sub-acute effects occur as a result of exposures lasting from a few days to one month (Eaton and Klaasson, 1996).

4.3.1 Acute and Sub-Acute Human Effects

The effects of acute human exposure to 2-ethylhexanol were limited to incidental cases involving exposure to more than one chemical. One study reported headaches, dizziness, fatigue, GI disorders and slightly decreased blood pressure in laboratory workers exposed to 2-ethylhexanol (Hollenbach *et al.* (in German) cited in WHO, 1993). Drawbacks to this 1972 study include no information on air concentrations of 2-ethylhexanol or other substances present in the workplace.

Acute respiratory symptoms were reported in the case study of a sensitive individual exposed to low air concentrations of multiple chemicals, of which 2-ethyl-1-hexanol was predominant, inside a newly completed campus building (Kamijima *et al.* 2002). Symptoms occurred in the individuals' office and within a faculty meeting room and included throat irritation, cough, sore eyes, headache and blurred vision. Concentrations of 2-ethylhexanol in the office (85.3 $\mu g/m^3$) and faculty meeting room (469 $\mu g/m^3$) were the highest of the 38 volatile organic compounds detected. The majority of VOCs were detected at concentrations below 3 $\mu g/m^3$ in the office (33 VOCs <3 $\mu g/m^3$) and in the meeting room (30 VOCs <3 $\mu g/m^3$) (Kamijima *et al.* 2002).

The International Programme on Chemical Safety (IPCS, 2001) classifies 2-ethylhexanol as an irritant of the eyes, skin, and respiratory tract, which may also affect the central nervous system. There is currently no Threshold Limit Value (TLV) for occupational exposure to 2-ethylhexanol (IPCS, 2001).

4.3.2 Acute Animal Effects

Table 4 lists the effects reported in animals following acute inhalation exposures to 2-ethylhexanol. No animal studies were identified for 2-ethylhexanol effects following sub-acute inhalation exposures.

Table 4 Effects Associated with Acute 2-Ethylhexanol Inhalation (Experimental Animals)

Effects Reported	Exposure Period	Air Concentration [a] ppm (mg EH/m^3)	Species	Reference
Death (LC_{50}):				
	8 hours	Saturated vapours >160 (850)	Rat	Smyth *et al.* cited in WHO, 1993
	6 hours	>235 (1252)	Rat	Treon, cited in WHO, 1993
	4 hours	> 167 (890) < 995 (5300)	Rat	OECD, 1995
Neurological/Irritation:				
CNS Depression; irritation of eyes, nose, throat and respiratory passages	6 hours	227 (1209)	Mice	Scala and Burtis, cited in WHO, 1993
CNS Depression; irritation of eyes, nose, throat and respiratory passages	6 hours	227 (1209)	Rat	Scala and Burtis, cited in WHO, 1993
CNS Depression; irritation of eyes, nose, throat and respiratory passages	6 hours	227 (1209)	Guinea Pig	Scala and Burtis, cited in WHO, 1993

[a] When both units of concentration were not provided in the literature, the following conversion factor and assumptions were used: mg/m^3 x 24.45/MW =ppm; MW=130.23, air at 25°C and 101.3 kPa (760mmHg) (Plog *et al.* 1996).

4.3.2.1 Neurological Effects

Depression of the central nervous system and laboured breathing were reported in mice, rats and guinea pigs exposed via inhalation to 227 ppm (1,209 mg/m^3) 2-ethylhexanol over a 6 hour period. The animals recovered within one hour of terminating exposure (Scala and Burtis, cited in WHO, 1993). In 1997, the U.S. EPA conducted a comprehensive review of publicly available chemical testing data for high production volume chemicals such as 2-ethylhexanol and concluded that the potential for 2-ethylhexanol neurotoxicity requires further study (U.S. EPA, 1998).

4.3.2.2 Other Effects

Irritation of the eyes, nose, throat and respiratory passages was reported in mice, rats and guinea pigs exposed via inhalation to 227 ppm (1,209 mg/m^3) 2-ethylhexanol over a 6 hour period. Full recovery occurred within one hour after exposure was terminated (Scala and Burtis, cited in WHO, 1993).

4.4 Sub-chronic and Chronic Effects

Sub-chronic effects generally occur following one to three months of exposure, while chronic effects occur as a result of repeated exposures for a period greater than 3 months (Eaton and Klaassen, 1996).

No human studies reporting chronic or sub-chronic effects from 2-ethylhexanol exposure were identified. Two sub-chronic studies were available for rats exposed via inhalation to 2-ethylhexanol. No chronic inhalation studies in animals were identified, however, long-term oral carcinogenicity studies of 2-ethylhexanol were available for mice and rats.

4.4.1 Sub-Chronic Animal Effects

Two studies on sub-chronic inhalation studies on animals were identified. Table 5 lists the NOAELs (No Observable Adverse Effect Level) reported in these studies.

Table 5 NOAEL Associated with Sub-Chronic 2-Ethylhexanol Inhalation (Rats)

Effects Reported	Exposure Period	Air Concentration [a] ppm (mg EH/m^3)	Species	Reference
Systemic Effects:				
NOAEL	90 days	≥120 (639)	Rat	Klimisch *et al.* 1998
Developmental Effects:				
NOAEL	20 days (gestation)	≥160 (850)	Rat	Nelson *et al.* cited in WHO, 1993

[a] When both units of concentration were not provided in the literature, the following conversion factor and assumptions were used: mg/m^3 x 24.45/MW =ppm; MW=130.23, air at 25°C and 101.3 kPa (760mmHg) (Plog *et al.* 1996).

4.4.1.1 Systemic Effects

In a 90 day sub-chronic inhalation toxicity study, no exposure-related effects were observed in rats exposed to 2-ethylhexanol vapour concentrations of 15, 40, or 120 ppm (Klimisch *et al.* 1998). Animals were observed for effects on body weight, weight gain, mortality, organ weight, clinical biochemistry (including liver peroxisome proliferation) and haematological parameters. A sub-chronic inhalation NOAEL of ≥120 ppm (639 mg/m^3) was reported based on the results of this study (Klimisch *et al.* 1998).

4.4.1.2 Reproductive and Developmental Effects

No significant maternal toxicity and no increase in fetus malformations were reported as a result of exposure of pregnant rats to approximately 850 mg/m^3 (160 ppm) 2-ethylhexanol for 7 hours a day throughout gestation (20 days) (Nelson *et al.* cited in WHO, 1993).

4.4.2 Chronic Animal Effects

In a study of chronic effects, 50 male and 50 female B6C3F$_1$ mice were exposed by gavage to 0, 50, 200 or 750 mg EH/kg body weight /day for five days a week, over an 18 month period (Astill *et al.* cited in WHO, 1998). No adverse, treatment-related effects were reported in mice exposed to 50 or 200 mg/kg body weight/day. At the high dose, statistically insignificant increases in the incidence of hepatocellular carcinomas and focal hyperplasia of the forestomach epithelium were observed. Other adverse effects reported at the high dose included body weight gain reductions, increased mortality and effects on haematological parameters. The study did not provide evidence of 2-ethylhexanol carcinogenicity in chronically exposed mice (WHO, 1998).

In a 2 year study, groups of 50 male and 50 female Fischer F344 rats were exposed by gavage to 0, 50, 150 or 500 mg EH/kg body weight/day for 5 days a week (Astill *et al.* cited in WHO, 1998). No adverse effects were reported at the lowest dose level (50 mg/kg body weight/day). Significant reductions in body weight, laboured breathing and poor general condition were observed in rats in the mid and high dose groups. Increased mortality occurred in females in the high dose group and an increased incidence of bronchopneumonia, due to aspiration of stomach contents, occurred in both males and females of the high dose group. The study did not provide evidence of 2-ethylhexanol carcinogenicity in chronically exposed rats (WHO, 1998).

4.5 Summary of Adverse Health Effects of 2-Ethylhexanol Inhalation

In vivo studies of liver enzymes and liver weights reported adverse effects in rodents exposed orally and by gavage to 2-ethylhexanol (effects occurring at doses $\geq$ 320 mg/kg body weight/day). *In vitro* studies of rat hepatocytes suggest a dose-dependent response for 2-ethylhexanol induced liver toxicity. Numerous *in vivo* and *in vitro* studies conclude that 2-ethylhexanol was not genotoxic. Two long-term ingestion studies in mice and rats concluded that 2-ethylhexanol was not carcinogenic.

A case study of a sensitive individual exposed to 2-ethylhexanol off-gassing from new materials present in her workplace, reported acute effects (headaches, blurred vision, throat and eye irritation, cough) at air concentrations measured at 85.3 $\mu g/m^3$ and 469 $\mu g/m^3$. Another study of laboratory workers reported similar symptoms as well as dizziness, fatigue and GI disorders. Both studies involved exposure to other substances that may confound the reported results, however, acute inhalation studies in mice, rats and guinea pigs also reported effects on the central nervous system and irritation of the eyes and throat following 2-ethylhexanol inhalation. Based on the data available in 1997, the U.S. EPA has concluded that further study is required to assess the potential neurotoxicity of 2-ethylhexanol. One 1998 study reported a NOAEL $\geq$639 mg/m^3 (highest dose) for systemic effects in rats following sub-chronic inhalation exposure to 2-ethylhexanol.

4.6 Effects on Vegetation

Little is known about the direct effects of volatile organic compounds (VOCs) on plants. A search of ecological databases (*i.e.,* Web of Science, Biological Abstracts, Toxnet (available at http://toxnet.nlm.nih.gov/), and Ecotox (available at http://www.epa.gov/ecotox/)) was conducted for literature describing the effects of 2-ethylhexanol on terrestrial and aquatic

vegetation. The search resulted in the identification of only one research article on the effect of 2-ethylhexanol in liquid media on algae. Nothing has been reported for effects on terrestrial vegetation.

Dave *et al.* (1979) evaluated the effect of a number of different compounds on the growth of the algal species *Chlorella emersonii* (strain 211, Cambridge Culture Collection of Algae and Protozoa). The *Chlorella emersonii* batch cultures were grown in an artificial media at the following conditions; 25% dilution of artificial media, aerated at 10 $dm^3 h^{-1}$, at a temperature of 25 °C, with a light intensity of 10 W m^{-2}) at three different levels of 2-ethylhexanol (0, 10, 50, and 100 mg dm^3). The 2-ethylhexanol treatment severely inhibited growth rate of the algae cultures at 50 and 100 mg dm^3, where as at 10 mg dm^3 a slight stimulation was observed. The calculated EC_{50} was 10-50 mg dm^3 for both exponential growth rate and standing stock (48h).

5.0 AIR SAMPLING AND ANALYTICAL METHODS

5.1 Reference Methods

Air sampling and analytical methods for 2-ethylhexanol used in practice by established agencies were reviewed. The results of the review indicate that reference air monitoring methods for 2-ethylhexanol are limited to a method that has been developed, tested and reported by the Occupational Safety and Health Administration (OSHA).

5.1.1 OSHA Chemical Sampling Information (CSI) for 2-Ethylhexanol

The OSHA has developed a non-validated method for 2-ethylhexanol that is suitable for occupational, personal and area monitoring. The methodology used by the OSHA consists of collecting 2-ethylhexanol on charcoal solid sorbent tubes with subsequent chemical analysis by gas chromatography with flame ionization detection (GC/FID) (OSHA, 1992). Sampling is conducted by drawing air through a solid sorbent tube (coconut shell charcoal, 100 mg in the front section and 50 mg in the back section) using a personal sampling pump. The suggested flow rate is less than 0.2 L/min and the maximum volume collected is 60 L. The contents of the tube are desorbed with methylene chloride and the desorbate is analyzed by GC/FID. The level of detection for concentrations of 2-ethylhexanol using this method has not been reported.

5.2 Alternative, Emerging Technologies

Reports, journal articles, conference proceedings and other sources known to contain information on ambient measurement methods for chemicals such as 2-ethylhexanol were reviewed to determine the current status of alternative and emerging technologies. The results of the review indicate a general lack of technologies for ambient monitoring of 2-ethylhexanol. Despite this need a handful of examples of alternative and emerging technologies have been developed and reported.

The National Institute for Occupational Safety and Health (NIOSH) has developed a method for determining concentrations of certain alcohols in air that, although not recommended, has been successfully used for 2-ethylhexanol (NIOSH, 1994). This method consists of collecting 2-ethylhexanol on charcoal solid sorbent tubes with subsequent chemical analysis by GC/FID. Sampling is conducted by drawing air through a solid sorbent tube (coconut shell charcoal, 100 mg in the front section and 50 mg in the back section) using a personal sampling pump. The suggested flow rate is 0.2 L/min and the maximum volume collected is 10 L. The contents of the tube are desorbed with carbon disulfide and the desorbate is analyzed by GC/FID. The level of detection for concentrations of 2-ethylhexanol using this method has been reported to be in the range of 123 to 494 mg/m^3 (23 to 93 ppmv).

Andersson *et al.* (1984) suggest collecting 2-ethylhexanol on charcoal solid sorbent tubes similar to the NIOSH and OSHA methods but with subsequent chemical analysis by gas chromatography with mass spectrometry (GC/MS). The level of detection for concentrations of 2-ethylhexanol using this method has been reported to be in the μg/m^3 range.

A passive gas badge sampler has been developed to measure concentrations of organic vapours (including 2-ethylhexanol) in air as an alternative to the standard active pump sampling techniques (SKC Inc., 2004). The advantages of this sampler are that there are no moving parts to break down, regular flow calibration is unnecessary, and no bulky, expensive pumps are required (Brown and Wright, 1994; Levin and Lindahl, 1994). The badge is exposed to ambient conditions for a set period of time (usually a much longer period than for active pump sampling) and then analyzed by thermal desorption with GC/FID detection. It can be used satisfactorily for determining 2-ethylhexanol concentrations in air under a range of atmospheric conditions.

6.0 AMBIENT GUIDELINES OR OBJECTIVES

Current and/or recommended and proposed ambient guidelines and objectives of other jurisdictions in Canada, United States, and elsewhere were reviewed for 2-ethylhexanol. All jurisdictions have specific uses for their guidelines. These uses may include, but are not limited to:

- Reviewing permit applications for sources that emit air pollutants to the atmosphere;
- Investigating accidental releases or community complaints about adverse air quality for the purpose of determining follow-up or enforcement activity, and;
- Determining whether to implement temporary emission control actions under persistent adverse air quality conditions of a short-term nature.

6.1 Air Quality Guidelines and Objectives for 2-Ethylhexanol

The air quality guidelines and objectives available for 2-ethylhexanol are summarized in Table 6. Further details on the development and use of these guidelines or objectives by each jurisdiction are provided in Appendix A. Only five agencies of 22 reviewed have a guideline or objective for this chemical. Numerous agencies develop guidelines or objectives for hazardous chemicals using occupational exposure levels (OELs) or results from animal bioassay data and dividing it by safety or adjustment factors. However, this was not the case for 2-ethylhexanol. For example, the three types of OELs that are sometimes used by state agencies are: i) the American Conference of Governmental Industrial Hygienists (ACGIH) 8-hour time weighted average OEL (ACGIH, 2003); ii) the National Institute for Occupational Safety and Health (NIOSH) relative exposure level (REL) (NIOSH, 2003); and iii) the U.S. Occupational Safety and Health Administration (OSHA) 8-hour Permissible Exposure Limit (PEL) (OSHA, 2003). However, no occupational exposure criteria exist among ACGIH, NIOSH, and OSHA for 2-ethylhexanol.

6.1.1 Canada

The Ontario Ministry of the Environment (MOE, 1999) adopted an Ambient Air Quality Criterion (AAQC) of 600 $\mu g/m^3$ as a one-hour guideline based on odor. The Ontario MOE also uses the value of 600 $\mu g/m^3$ for a 30-minute maximum point of impingement (POI) guideline based on odor.

6.1.2 United States

Only four states of those reviewed have air quality guidelines for 2-ethylhexanol: Michigan, Oklahoma, Texas, and Vermont. Michigan uses an initial threshold screening level (ITSL) of 70 $\mu g/m^3$ (13 ppb) for an annual averaging time. The basis for this guideline is unknown. Oklahoma uses a maximum acceptable ambient concentration (MAAC) of 37,600 $\mu g/m^3$ (7,060 ppb) for a 24-hour averaging time. The basis for this guideline is also unknown.

Texas uses a short-term effects screening level (ESL) of 740 $\mu g/m^3$ (140 ppb) for a one-hour averaging time and a long-term effects screening level (ESL) of 74 $\mu g/m^3$ (14 ppb) for an annual averaging time. Both of these guidelines are based on odor. Finally, Vermont uses a hazardous

ambient air standard (HAAS) of 130 µg/m^3 (24 ppb) for a 24-hour averaging time. The basis for this guideline is unknown.

6.1.3 International Agencies

The New Zealand Ministry of Environment and Ministry of Health, the Netherlands National Institute of Public Health (RIVM, 2001), and WHO (2000) do not have air quality criteria for 2-ethylhexanol.

Table 6 Summary of Air Quality Guidelines for 2-Ethylhexanol

Agency	Guideline Title	Guideline Value [µg/m^3] Averaging Time: 1-hour	8-hour	24-hour	Annual
Ontario MOE	Ambient air quality criterion (AAQC):	600			
	Maximum point of impingement (POI) Guideline.	600 (30-min)			
ATSDR					
US EPA	No guideline exists.				
Arizona DEQ	No guideline exists.				
California EPA	No guideline exists.				
Indiana DEM	No guideline exists				
Louisiana DEQ	No guideline exists				
Massachusetts DEP	No guideline exists.				
Michigan DEQ	Initial threshold screening level (ITSL):				70
New Hampshire DES	No guideline exists				
New Jersey DEP	No guideline exists.				
North Carolina ENR	No guideline exists.				
Ohio EPA	No guideline exists.				
Oklahoma DEQ	Maximum acceptable ambient concentration (MAAC):			37,600	
Rhode Island DEM	No guideline exists.				
Texas CEQ	Effects screening level (ESL):	740			74
Vermont ANR	Hazardous ambient air standard (HAAS):			130	
Washington DOE	No guideline exists.				
Wisconsin DNR	No guideline exists.				
New Zealand MOE	No guideline exists.				
The Netherlands (RIVM)	No guideline exists.				
World Health Organization	No guideline exists.				

7.0 DISCUSSION

Establishing an ambient air quality guideline in the form of a concentration limit with a corresponding exposure duration (*i.e.*, averaging time) requires a number of factors to be taken into account, including:

- The nature of adverse health effects and conditions of exposure (*e.g.*, concentration and duration) associated with these effects;
- The estimated or actual degree of exposure of receptors, in particular those that may be sensitive to the air pollutant;
- The available technologies and associated economics for routinely or periodically monitoring for the pollutant in air, and;
- The availability and suitability of approaches for screening and estimating ambient ground-level concentrations in order to compare to the guidelines for permit applications or other situations.

2-Ethylhexanol is currently not an Environment Canada NPRI reportable substance and therefore no data on emissions or ambient outdoor air concentrations were available. Air concentrations ranging from <1 $\mu g/m^3$ to 10 $\mu g/m^3$ were reported in a Germany study of 2-ethylhexanol in indoor air.

The standard air monitoring method for 2-ethylhexanol is based on sorbent tube sampling. A reference air monitoring method for 2-ethylhexanol was developed tested and reported by OSHA.

Ambient air guidelines in the form of short-term (acute) and long-term (chronic) duration are discussed below for 2-ethylhexanol. Ideally, air quality guidelines serve to address exposures related to humans, animals, and vegetation. No direct exposure-related information was obtained for terrestrial vegetation; therefore the discussion emphasizes the effects of 2-ethylhexanol in human and animals.

7.1 Acute Exposure Conditions

Acute inhalation exposure studies in rats reported lethal exposure concentrations above 1252 mg/m^3 (6 hour exposure period) but less than 5300 mg/m^3 (4 hour exposure period). Symptoms of acute exposure of mice, rats, and guinea pigs to sub-lethal concentrations of 2-ethylhexanol (1209 mg/m^3) included CNS depression, laboured breathing, and irritation of eyes, nose, throat, and respiratory passages. Full recovery was reported within one hour after termination of exposure.

The acute human health effects of inhalation exposure to 2-ethylhexanol were limited to cases involving exposure to more than one chemical with limited or no information on air concentrations. Laboratory workers exposed to 2-ethylhexanol (concentration unknown) and other unidentified chemicals, reported headaches, dizziness, fatigue, GI disorders and slightly decreased blood pressure. A chemical sensitive individual exposed to 2-ethylhexanol (and other

VOCs) in a newly completed building reported throat irritation, eye irritation, cough, headache, and blurred vision. Measured air concentrations of 2-ethylhexanol were the highest among the 38 VOCs detected and ranged from 85.3 $\mu g/m^3$ to 469 $\mu g/m^3$.

The International Programme on Chemical Safety (IPCS) has classified 2-ethylhexanol as acutely irritant to the eyes, skin, and respiratory tract. Both the IPCS and the U.S. EPA have indicated a potential for neurotoxicity associated with acute 2-ethylhexanol exposure.

There are no acute inhalation criteria for occupational exposure to 2-ethylhexanol. Provincial and state agencies that have developed acute air quality guidelines (averaging times of 24-hours or less) include Ontario MOE, Texas CEQ, Oklahoma DEQ, and Vermont ANR.

The Ontario MOE established a 1-hour guideline of 600 $\mu g/m^3$ and a 30-minute maximum POI of 600 $\mu g/m^3$ based on odour. Similarly, the state of Texas established a 1-hour ESL of 740 $\mu g/m^3$ based on odour.

The two air quality objectives identified for 24-hour exposures to 2-ethylhexanol varied widely. The state of Oklahoma established a 24-hour MAAC of 37,600 $\mu g/m^3$ whereas the 24-hour HAAS for the state of Vermont is 130 $\mu g/m^3$. The basis for either of these guidelines is unknown.

7.2 Chronic Exposure Conditions

In two subchronic inhalation studies in rats, NOAELs of $\geq$639 mg/m^3 and $\geq$850 mg/m^3 were identified for systemic and developmental effects, respectively. No chronic inhalation studies in animals were identified. There were no human studies reporting effects from either sub-chronic or chronic exposure to 2-ethylhexanol.

Agencies that have developed chronic air quality guidelines (annual average) for 2-ethylhexanol include: Michigan and Texas. The basis for Michigan's ITSL of 70 $\mu g/m^3$ is unknown. Texas established a long-term ESL of 74 $\mu g/m^3$ based on odor.

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APPENDIX A
Air Quality Objectives for 2-Ethylhexanol Development and Use

Agency: Ontario Ministry of the Environment (OME).
Air Quality Guideline: Ambient Air Quality Criterion (AAQC) = 600 µg/m^3.
Averaging Time To Which Guideline Applies: 1-hour averaging time.
Basis for Development: Limiting effect based on odor.
Date Guideline Developed: Unknown.
How Guideline is Used in Practice: Used by Ontario Ministry of Environment (OME) to represent human health or environmental effect-based values not expected to cause adverse effects based on continuous exposure.
Additional Comments: AAQC is not used by OME to permit stationary sources that emit 2-ethylhexanol to the atmosphere. A "point of impingement" standard is used to for permitting situations.
Reference and Supporting Documentation: Ontario Ministry of the Environment. 1999. Summary of Point Of Impingement Standards, Point Of Impingement Guidelines, and Ambient Air Quality Criteria (AAQC). Standards Development Branch, Ontario Ministry of the Environment, Toronto, ON. November 1999. 12 pp.

Agency: Ontario Ministry of the Environment (OME).
Air Quality Guideline: Maximum point of impingement (POI) Standard = 600 $\mu g/m^3$.
Averaging Time To Which Guideline Applies: 30-minute averaging time.
Basis for Development: Not stated.
Date Guideline Developed: Unknown.
How Guideline is Used in Practice: Used by OME to review permit applications for stationary sources that emit 2-ethylhexanol to the atmosphere.
Additional Comments: n/a
Reference and Supporting Documentation: Ontario Ministry of the Environment. 1999. Summary of Point Of Impingement Standards, Point Of Impingement Guidelines, and Ambient Air Quality Criteria (AAQC). Standards Development Branch, Ontario Ministry of the Environment, Toronto, ON. November 1999. 12 pp.

Agency: US Agency for Toxic Substances and Disease Registry (ATSDR).
Air Quality Guideline: ATSDR does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: Agency for Toxic Substances and Disease Registry (ATSDR). 2003. Minimal Risk Levels (MRLs) for Hazardous Substances. ATSDR, Public Health Service, US Department of Health and Human Services. Atlanta, GA. Available at: http://www.atsdr.cdc.gov/mrls.html (accessed 31 December 2003).

Agency: US Environmental Protection Agency (EPA).
Air Quality Guideline: US EPA does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: US Environmental Protection Agency. 2003. Integrated Risk Information System. Available at: http://www.epa.gov/iris/ (accessed 31 December 2003).

Agency: Arizona Department of Health Services (DHS).
Air Quality Guideline: Arizona DHS does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: Arizona Department of Health Services (DHS). 1999. 1999 Update – Arizona Ambient Air Quality Guidelines (AAAQGs). Report prepared for Arizona Department of Environmental Quality, Air Programs Division. Arizona DHS, Office of Environmental Health, Phoenix, AZ. 11 May 1999. 20 pp.

Agency: California Environmental Protection Agency (Cal EPA).
Air Quality Guideline: Cal EPA does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: California Environmental Protection Agency (Cal EPA). 1999. Determination of Acute Reference Exposure Levels for Airborne Toxicants. Office of Environmental Health Hazard Assessment, Air Toxicology and Epidemiology Section, Cal EPA. Oakland, CA. March 1999. California Office of Environmental Health Hazard Assessment (OEHHA)/Air Resources Board (ARB). 2003. Approved Chronic Reference Exposure Levels and Target Organs. Table 3 (last updated 4 December 2003). Available at: www.arb.ca.gov/toxics/healthval/chronic.pdf (accessed 31 December 2003).

Agency: Indiana Department of Environmental Management (IDEM).
Air Quality Guideline: IDEM does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: Indiana Department of Environmental Management (DEM). 2002. Office of Air Quality Programs. Indiana DEM, Office of Air Quality, Indianapolis, IN. Available at: http://www.in.gov/idem/air/programs/modeling/policy.html (accessed 31 December 2003).

Agency: Louisiana Department of Environmental Quality (DEQ).
Air Quality Guideline: Louisiana DEQ does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: *Louisiana Administrative Code (LAC). Title 33 Environmental Quality, Part III Air, Chapter 51. Comprehensive Toxic Air Pollutant Emission Control Program. Louisiana Department of Environmental Quality, Baton Rouge, LA.*

Agency: Massachusetts Department of Environmental Protection (DEP).
Air Quality Guideline: Massachusetts DEP does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: Massachusetts Department of Environmental Protection (DEP). 1995. Revised air guidelines [updated list of 24-hour average Threshold Effects Exposure Limit (TEL) values and annual average Allowable Ambient Limit (AAL) values]. Massachusetts DEP, Boston, MA. 6 December 1995. Memorandum. Available at: http://www.state.ma.us/dep/ors/files/aallist.pdf (accessed 31 December 2003).

Agency: Michigan Department of Environmental Quality (DEQ).
Air Quality Guideline: Initial threshold screening level (ITSL) = 70 $\mu g/m^3$ (13 ppb).
Averaging Time To Which Guideline Applies: Annual averaging time.
Basis for Development: Unknown.
Date Guideline Developed: 1993.
How Guideline is Used in Practice: There are two basic requirements of Michigan air toxic rules. First, each source must apply the best available control technology for toxics (T-BACT). After the application of T-BACT, the emissions of the toxic air contaminant cannot result in a maximum ambient concentration that exceeds the applicable health based screening level for non-carcinogenic effects (ITSL). Application of an ITSL is required for any new or modified emission source or sources for which a permit to install is requested and which emits a toxic air contaminant.
Additional Comments: The applicable air quality screening level for chemical treated as non-carcinogens by Michigan DEQ is the ITSL. There are two health based screening levels for chemical treated as carcinogens by Michigan DEQ: the initial risk screening level (IRSL) – based on an increased cancer risk of one in one million, and the secondary risk screening level (SRSL) – based on as an increased cancer risk of 1 in 100,000.
Reference and Supporting Documentation: *Michigan Administrative Code (MAC). Air Pollution Control Rules. Part 2 Air Use Approval, R 336.1201 - 336.1299. Air Quality Division, Department of Environmental Quality. Lansing, MI.* Michigan Department of Environmental Quality (DEQ). 2003. Air Toxics. Michigan DEQ, Air Quality Division, Lansing, MI. Available at: http://www.michigan.gov/deq/0,1607,7-135-3310_4105---,00.html (accessed 31 December 2003).

Agency: New Hampshire Department of Environmental Services (DES).
Air Quality Guideline: New Hampshire DES does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: *New Hampshire Administrative Rule. Chapter Env-A 1400. Regulated Toxic Air Pollutants. New Hampshire Department of Environmental Services. Concord, NH.*

Agency: New Jersey Department of Environmental Protection (DEP).
Air Quality Guideline: Applicants are required to carry out a risk assessment in conjunction with applying for an air pollution control pre-construction permit. New Jersey DEP normally uses US EPA toxicological criteria from the Integrated Risk Information System. However in the case of 2-ethylhexanol, US EPA does not have toxicological criteria for this compound.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: *New Jersey Administrative Code (NJAC). Title 7, Chapter 27, Subchapter 8. Permits and Certificates for Minor Facilities (and Major Facilities without an Operating Permit). New Jersey Department of Environmental Protection. Trenton, NJ.* New Jersey Department of Environmental Protection. 1994. Technical Manual 1003. Guidance on Preparing a Risk Assessment for Air Contaminant Emissions. Air Quality Permitting Program, Bureau of Air Quality Evaluation, New Jersey Department of Environmental Protection. Trenton, NJ. Revised December 1994.

Agency: North Carolina Department of Environment and Natural Resources (ENR).
Air Quality Guideline: North Carolina ENR does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: *North Carolina Administrative Code (NCAC). North Carolina Air Quality Rules 15A NCAC 2D.1100 – Air Pollution Control Requirements (Control of Toxic Air Pollutants). North Carolina Department of Environment and Natural Resources. Raleigh, NC.* *North Carolina Administrative Code (NCAC). North Carolina Air Quality Rules 15A NCAC 2Q.0700 – Air Quality Permit Procedures (Toxic Air Pollutant Procedures). North Carolina Department of Environment and Natural Resources. Raleigh, NC.*

Agency: Ohio Environmental Protection Agency (EPA).
Air Quality Guideline: Ohio EPA does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: Ohio Environmental Protection Agency (EPA). 2003. Review of New Sources of Toxic Emissions. Air Toxics Unit, Division of Air Pollution Control, Ohio EPA. Columbus, OH. 11 pp. Available at: http://www.epa.state.oh.us/dapc/atu/atu.html (accessed 31 December 2003). Ohio Environmental Protection Agency (Ohio EPA). 1994. Review of New Sources of Air Toxic Emissions. Proposed for Public Comment. Division of Air Pollution Control, Ohio EPA, Columbus, OH. January 1994. 31 pp.

Agency: Oklahoma Department of Environmental Quality (DEQ).
Air Quality Guideline: Maximum acceptable ambient concentration (MAAC) = 37,600 µg/m^3 (7,060 ppb).
Averaging Time To Which Guideline Applies: 24-hour averaging time.
Basis for Development: Unknown.
Date Guideline Developed: Not stated.
How Guideline is Used in Practice: MAACs are used by Oklahoma DEQ to review permit applications for sources that emit 2-ethylhexanol to the atmosphere.
Additional Comments: n/a
Reference and Supporting Documentation: *Oklahoma Administrative Code (OAC). Title 252. Chapter 100. Air Pollution Control. 100:252-41 - Control of Emission of Hazardous and Toxic Air Contaminants. Oklahoma Department of Environmental Quality. Oklahoma City, OK.* Oklahoma Department of Environmental Quality (DEQ). 2003. Total Air Toxics Partial Listing [maximum acceptable ambient concentrations (MAAC) for air toxics]. Oklahoma City, OK. Available at: http://www.deq.state.ok.us/AQDNew/toxics/listings/pollutant_query_1.html (accessed 31 December 2003).

Agency: Rhode Island Department of Environmental Management (DEM).
Air Quality Guideline: Rhode Island DEM does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: *Rhode Island Department of Environmental Management. 1992. Air Pollution Control Regulation No. 22. Division of Air and Hazardous Materials, Rhode Island Department of Environmental Management. Providence, RI. Amended 19 November 1992.*

Agency: Texas Commission on Environmental Quality (CEQ) – formerly Texas Natural Resource Conservation Commission (TRNCC).
Air Quality Guideline: Short-term effects screening level (ESL) = 740 µg/m^3 (140 ppb). Long-term effects screening level (ESL) = 74 µg/m^3 (14 ppb).
Averaging Time To Which Guideline Applies: 1-hour averaging time for short-term ESL. Annual averaging time for long-term ESL.
Basis for Development: Short-term Effects Screening Level – unknown other than it is based on odor. Long-term Effects Screening Level – unknown other than it is based on odor.
Date Guideline Developed: Not stated.
How Guideline is Used in Practice: ESLs are used to evaluate the potential for effects to occur as a result of exposure to concentrations of constituents in air. ESLs are based on data concerning health effects, odor nuisance potential, effects with respect to vegetation, and corrosion effects. They are not ambient air standards. If predicted or measured airborne levels of a chemical do not exceed the screening level, adverse health or welfare effects would not be expected to result. If ambient levels of constituents in air exceed the screening levels, it does not necessarily indicate a problem, but rather, triggers a more in-depth review.
Additional Comments: n/a
Reference and Supporting Documentation: Texas Natural Resource Conservation Commission (TNRCC) 2001. Toxicology & Risk Assessment (TARA) Section Effects Screening Levels. Available at: http://www.tnrcc.state.tx.us/permitting/tox/index.html (accessed 31 December 2003).

Agency: Vermont Agency of Natural Resources (ANR).
Air Quality Guideline: Hazardous ambient air standard (HAAS) = 130 $\mu g/m^3$ (24 ppb).
Averaging Time To Which Guideline Applies: 24-hour averaging time.
Basis for Development: Unknown other than it is believed by Vermont ANR to cause short-term irritant effects.
Date Guideline Developed: Not stated.
How Guideline is Used in Practice: HAASs are used by Vermont ANR to review permit applications for stationary sources that emit 2-ethylhexanol to the atmosphere.
Additional Comments: n/a
Reference and Supporting Documentation: Vermont Air Pollution Control Regulations. 2001. Appendix C - Rule 5-261 - Control of Hazardous Air Contaminants, Vermont Air Pollution Control Regulations. State of Vermont Agency of Natural Resources. Air Pollution Control Division. Waterbury, VT. 29 November 2001. 187 pp.

Agency: Washington State Department of Ecology (DOE).
Air Quality Guideline: Washington DOE does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: *Washington Administrative Code (WAC). Chapter 173-460 WAC. Controls For New Sources Of Toxic Air Pollutants. Washington State Department of Ecology. Olympia, WA.*

Agency: Wisconsin Department of Natural Resources (DNR).
Air Quality Guideline: Wisconsin DNR does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: *Wisconsin Administrative Code (WAC). Air Pollution Control Rules. Chapter NR 445. Control of Hazardous Pollutants. Wisconsin Department of Natural Resources. Madison WI.*

Agency: New Zealand Ministry for the Environment (MOE) and New Zealand Ministry of Health (MOH).
Air Quality Guideline: New Zealand MOE and MOH do not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: New Zealand Ministry for the Environment and Ministry of Health (New Zealand). 2000. Proposals for Revised and New Ambient Air Quality Guidelines. Discussion Document. Air Quality Technical Report No 16. Prepared by the Ministry for the Environment and the Ministry of Health. December 2000. 79 pp.

Agency: The Netherlands National Institute of Public Health and the Environment (RIVM)
Air Quality Guideline: RIVM does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: The Netherlands National Institute of Public Health and the Environment (RIVM). 2001. Re-evaluation of human-toxicological maximum permissible risk levels. RIVN Report 711701 025. RIVN, Bilthoven, The Netherlands. March 2001. 297 pp.

Agency: World Health Organization (WHO)
Air Quality Guideline: WHO does not have an air quality guideline for this chemical.
Averaging Time To Which Guideline Applies: n/a
Basis for Development: n/a
Date Guideline Developed: n/a
How Guideline is Used in Practice: n/a
Additional Comments: n/a
Reference and Supporting Documentation: World Health Organization (WHO). 2000. Air Quality Guidelines for Europe, 2nd Edition. WHO Regional Publications, European Series, No. 91. WHO Regional Office for Europe, Copenhagen. 273 pp.